Development of a Synoptic Climatology for the Northeast Gulf of Alaska[1]

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ABSTRACT

The subjective, sea level pressure-based, synoptic climatologies of Sorkina and Putnins have been specialized for the coastal region of southern Alaska. The results of the subjective typing were compared to the automated correlation technique for surface chart typing proposed by Lund. The subjective and automated approaches point to four persistent patterns: the Aleutian low, the low over the southern Gulf of Alaska, high pressure centered over the eastern Gulf of Alaska, and high pressure centered over the western Gulf of Alaska. Beyond these four patterns, migratory low-pressure centers were divided into various groups.

Matching individual synoptic charts to the map patterns, or sequencing, was done both subjectively and objectively by correlation with the National Meteorological Center grid point analyses. For the period 1968–77 75% of the twice daily sea level pressure charts could be sequenced objectively by matching one of the subjective subtypes with a correlation > 0.7. Correlation-based techniques for determining types, as in the Lund approach, and as a basis for sequencing are not sensitive to high-wavenumber features in the fields or features near the edge of the region when compared to subjective techniques.

1. Introduction

This paper describes the approach used to identify, or label, climatological types for the coast of southern Alaska from Yakutat to Kodiak Island (Fig. 1). A synoptic climatology regards patterns of weather (clouds, rain, wind, etc.) as an implicit function of the static sea level pressure (SLP) distribution (Barry and Perry, 1973). It is most appropriate in regions where a proportion of features form and/or decay *in situ* or are persistent. Since the Gulf of Alaska is often the decay center for storms in the Pacific, this approach is used as a working hypothesis. The static approach differs from a kinematic approach in which synoptic weather maps are classified in terms of principal storm tracks. The east coast of the United States is an example where a kinematic approach would be more appropriate.

A major use of SLP based synoptic climatologies is to stratify subsynoptic-scale spatial variations in parameters such as rainfall, local winds and surface temperatures by establishing correlations with large-scale patterns (Singh *et al.*, 1978; Suckling and Hay, 1978). The results of our study were used to stratify coastal winds under strong orographic influence by synoptic map type for an oil spill trajectory model. The intent was to retain the influence of daily wind variability on the dispersion of trajectories as part

of a climatological assessment. This paper, however, is restricted to the development and interpretation of the synoptic climatology.

There are two approaches to map typing (which we define as determining representative pressure patterns)—these can be referred to as objective, or at least automated, and subjective. Objective typing can be considered a pattern recognition problem involving digitized weather maps. Such techniques are generally based on principal component analysis, factor analysis and their close relatives (Kendall and Stuart, 1975) or pattern correlation techniques (Lund, 1963). The subjective approach involves a meteorologist assigning daily weather maps into different categories. A rationale for subjective typing is that in order for patterns to form a successful climatology, the underlying meteorological processes leading to these patterns should be recognizable.

We established six subjectively derived SLP weather types which were subdivided into 13 subtypes for the northeast Gulf of Alaska (NEGOA) region. Candidate patterns were derived by combining and modifying patterns from two previous studies by Sorkina (1963) and Putnins (1966). The final types were obtained by modifying the candidate patterns by comparisons with the fall 1977 through summer 1978 hand-analyzed surface charts from the National Meteorological Center. These comparisons also indicated the necessity of including subtypes within a type. Subtypes contain the same general
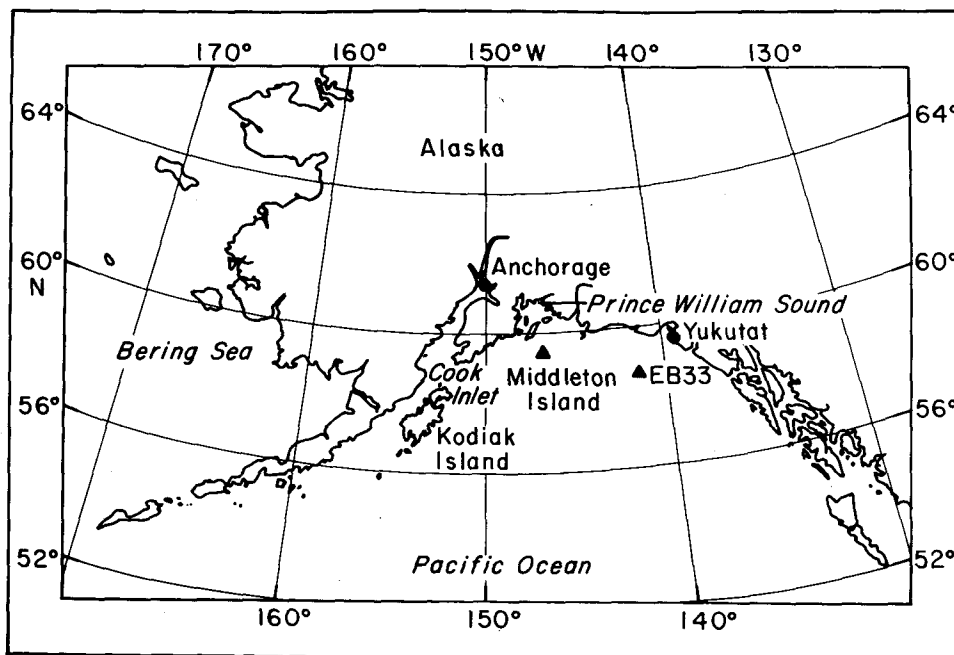
FIG. 1. Location map for the Gulf of Alaska.

distribution of features and meteorological basis as their parent types but represent slight variations in locations of those features that cause changes in the orientation of the geostrophic wind along the NEGOA coastline.

Digitized sea level pressure grids for the Northern Hemisphere produced by the National Meteorologi-

FIG. 2. National Meteorological center 47 × 51 octagonal grid. The subset of 24 points used in the study are shown by the cross-hatched region.

cal Center (NMC) were an additional resource for this study (Jenne, 1975). The fields used in this study were for the years 1968–77. Each subjective subtype was digitized on the same mesh as the NMC grid for 24 common points (Fig. 2). An individual daily chart may then be quickly assigned to a type (which we define as sequencing) by computing its correlation with each of the subjective types. Such a procedure forms the basis for duration and transition probability calculations for the various patterns.

The second approach to typing NEGOA consisted of applying the pattern correlation technique (Lund, 1963; Blasing, 1975) to the NMC digitized sea level pressure charts. This technique consists of forming the correlation of each day's pattern with those of all other days within the sample period. The pattern of the day with the highest number of correlations with other days greater than a prescribed cutoff value becomes type A. All patterns that correlate greater than the cutoff value with type A are removed from the sample and the procedure is repeated to find type B; the analysis is continued until the data are exhausted.

The next two sections of the paper describe the synoptic weather types obtained by the two methods; the remainder of the paper discusses the limitations in applying the synoptic climatology.

2. Subjective weather patterns for coastal Gulf of Alaska

Two previous studies to find type patterns, duration and transition probabilities that cover southern
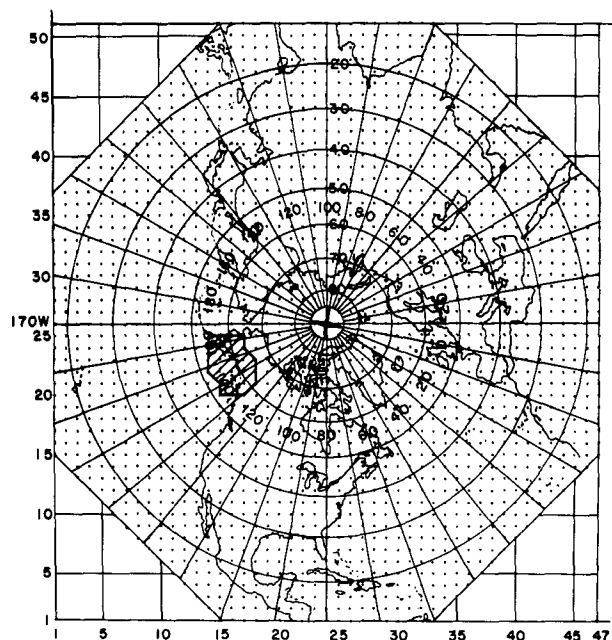
TABLE 1. Subjective weather types for the Northeast Gulf of Alaska.

Type	Description	Sorkina type	Putnins type	Dominant season
I	Low in Gulf of Alaska	4c	A', A$_1$, G, H	winter
II	Aleutian Low	5b	A, C, E, A$_c$	winter, spring, fall
III	High pressure over northern and interior Alaska	6a	D, B, D$_1$	winter
IV	Low-pressure center over central Alaska	1a	A", A$_3$, F	summer
V	Pacific anticyclone	1b, 5a	A'", A$_2$, E', E$_1'$	summer
VI	Stagnating low off of Queen Charlotte Islands	7a	D', E", E$_1$, F$_1$	spring, fall

Alaska are Sorkina (1963) and Putnins (1966). Sorkina provides a description of the surface circulation patterns over the entire North Pacific Ocean. Fifteen patterns were obtained based on 16 000 daily synoptic maps spanning 47 years (1899–39 and 1954–59). Each pattern is subjectively justified on meteorological grounds. Seasonal duration and transitional probability statistics are established. The climatology is based on three underlying regional physical processes which can be combined and rearranged to make each pattern. These are zones of cyclogenesis, formation and persistence of high-pressure regions, and regions for stagnation of lows. Sorkina indicates that high-pressure areas and zones of cyclogenesis tend to alternate at midlatitudes, while regions of stagnation and zonal bands of rapid movement for lows alternate at higher latitudes. She shows that each of her patterns is seasonally persistent and tends toward transition to other specific patterns.

Sorkina's patterns were applied to a new data set, the daily Pacific surface analyses at 1800 GMT from September 1977 to December 1977. An analysis of map sequences for the middle and eastern North Pacific showed that the daily maps would resemble one of Sorkina's patterns in general character for several days, followed by 3 or 4 days of less identifiable character as the cyclones moved rapidly from cyclogenic regions to stagnation regions, where the maps would again resemble a type pattern for another few days. Sorkina's patterns were useful in our first attempt to stratify a new data set, particularly because of the physical justification of each type. Unfortunately, her type patterns cover the entire North Pacific and do not adequately resolve the comparatively small and peripheral Gulf of Alaska.

Putnins (1966) restricted his study to Alaska and surrounding waters. Putnins' 22 patterns were also obtained from a large data set. Weather maps, both surface and 500 mb, for the period 1 January 1945–31 March 1963, were used to determine types "in such a way that for every date of this period a specific baric weather pattern could be assigned." Duration and transition frequencies were also found. The 500 mb patterns were used to assign either a cyclonic, anticyclonic or mixed designation to the flow pattern aloft. Most of Putnins' patterns relate to one or another of Sorkina's more general patterns and illustrate details of flow features not seen in Sorkina's patterns. However, several of the infrequently occurring types seem arbitrary. Furthermore, his patterns apply to all of Alaska so that the difference between any two patterns is sometimes due to a difference occurring far from the coastal Gulf of Alaska.

Our six basic types were derived by 1) incorporating the broad meteorological distinctions illuminated by Sorkina; 2) grouping Putnins' patterns that are redundant in the GOA region; and 3) using fall, winter, spring and summer of 1977–78 SLP analyses to refine the detailed features of Putnins' patterns for the GOA region.

The six types (Table 1) represented by 13 subtype patterns are shown in Fig. 3. The contour levels and intensities in each chart are considered arbitrary. Most of Putnins' 22 patterns can be incorporated into these slightly more general patterns, and most of the 1977–78 surface maps subjectively resemble one or another of the 13. Subtypes consider the same meteorological conditions as the parent types, but represent slight variation in location of pressure centers, which results in changes of wind directions over NEGOA. For example, the major subtypes for Type 1 are derived by relocating the low center along the coast.

NMC sea level pressure analyses for 1968–77 were used to develop frequency and transition statistics for the subjective types. The analyses are on a polar stereographic grid with a mesh length of 381 km at 60°N latitude. The analyzed maps depend on the availability of ship observations at a given map time and are subject to interpolation and smoothing errors introduced by the analysis procedures. This was particularly noticeable as a lack of packing of the isobars along the coastline when comparing the grid point analyses to hand-analyzed charts in Type 1 or Type 6 synoptic conditions.

A subset of 24 grid points was extracted from each 12 h map for the NEGOA region (Fig. 2). By digitizing each subtype at the same grid points, the correlation between each map and the 13 subtypes was computed by

$$r_{it} = \sum_{m=1}^{24} P_{im} P_{tm} \left(\sum_{m=1}^{24} P_{im}{}^2 \sum_{m=1}^{24} P_{tm}{}^2 \right)^{-1/2}, \quad (1)$$
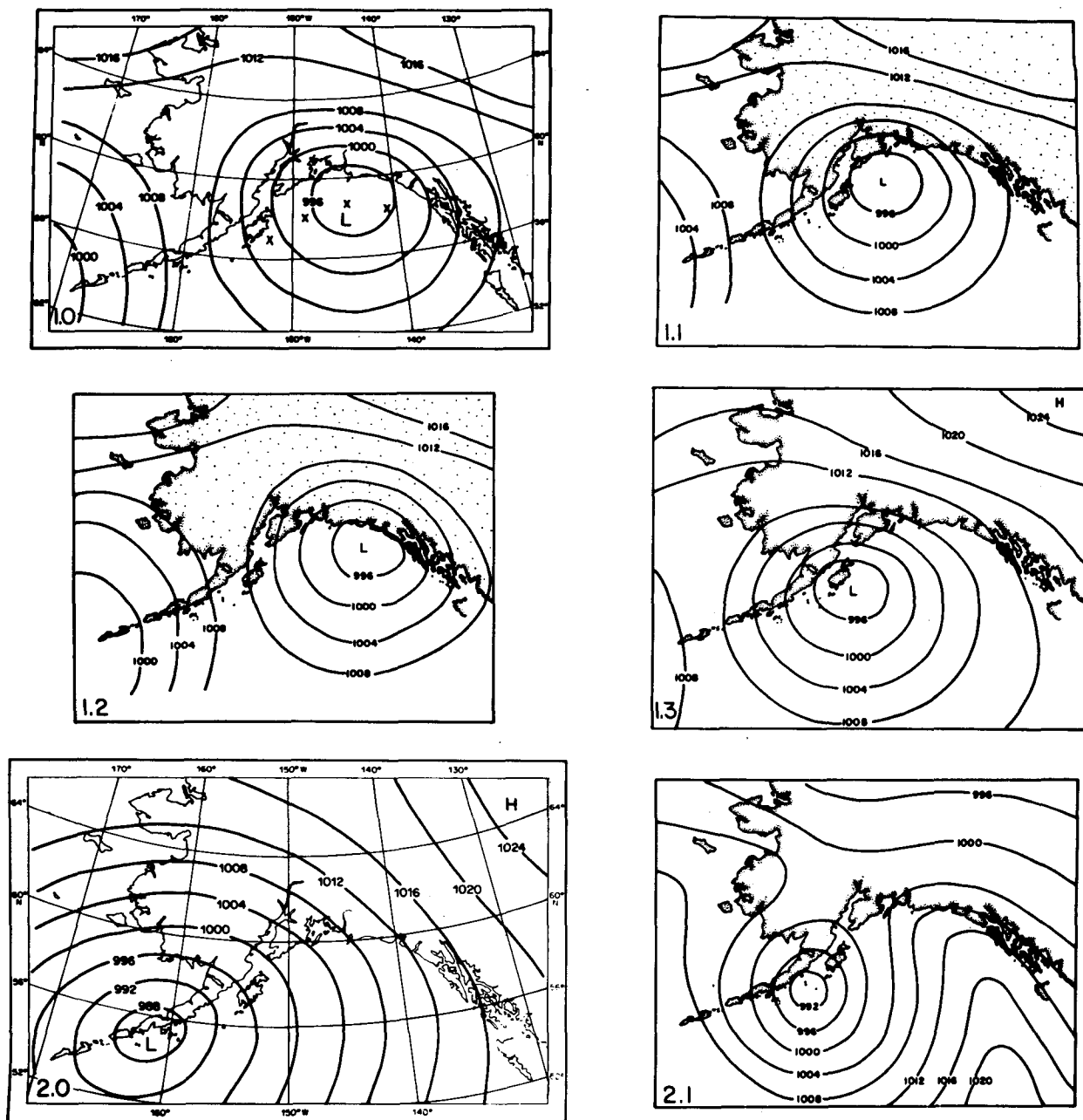
FIG. 3. Subjective weather subtypes 1.0–6.1. The whole number indicates the primary type and the fractional number indicates the subtype within the type.

where P_{im} and P_{tm} represent the deviation of pressures from the map average for date i and type t at grid point m. The weather type with the largest correlation was assigned to that daily map. We will use the term "correlation sequencing" for this method of assigning a type to each daily pressure field.

The percent of occurrence of each type by year and season is given in Table 2 while the percent of occurrence of each subtype is given in the Appendix and graphed in Fig. 4. The Aleutian low (pattern 2) is dominant in all seasons. Pattern 3 (high in interior

of Alaska) is confirmed as a winter pattern and the east Pacific high pressure (pattern 5) as a summer pattern. Lows to the north (pattern 4) peak in summer and lows to the southeast (pattern 6) peak in winter. The same tables also list transition probabilities.

3. Automated weather typing by pattern correlation

This section discusses an alternate approach to map typing, the pattern correlation technique (Lund,
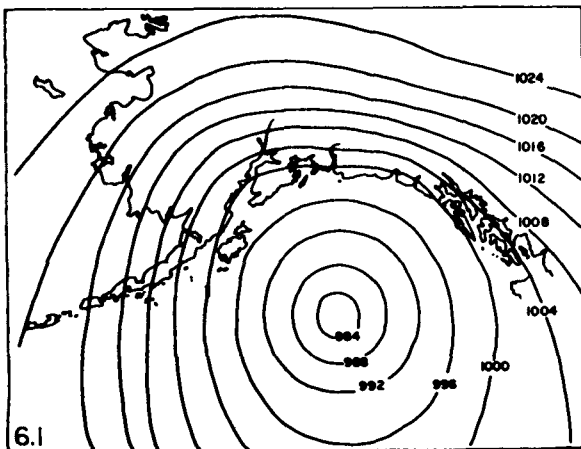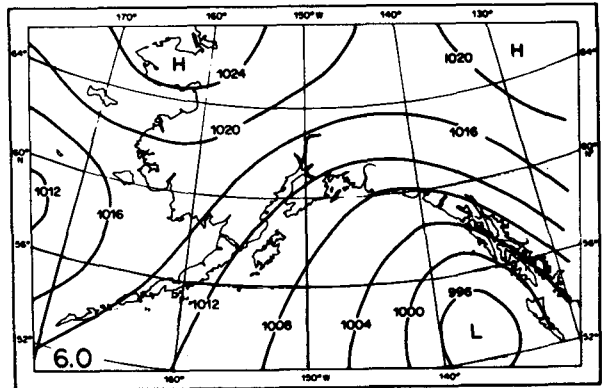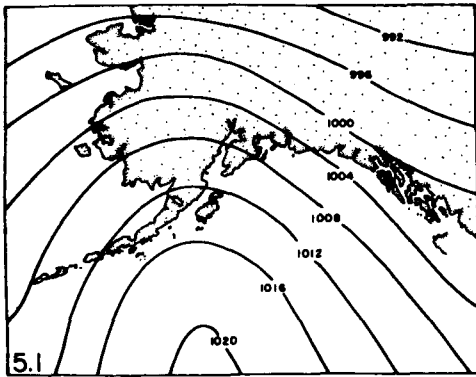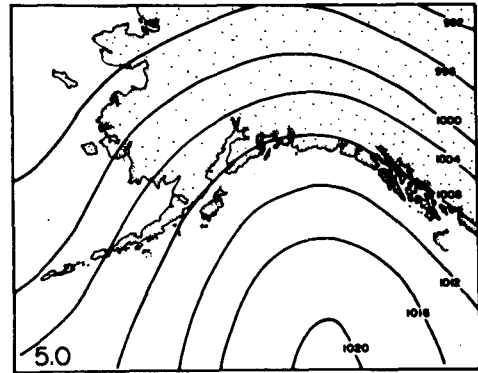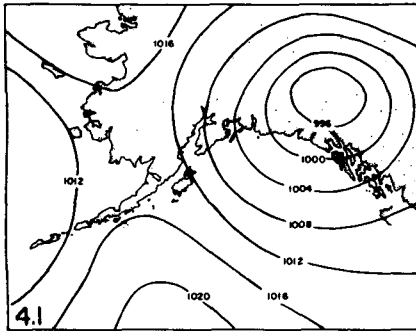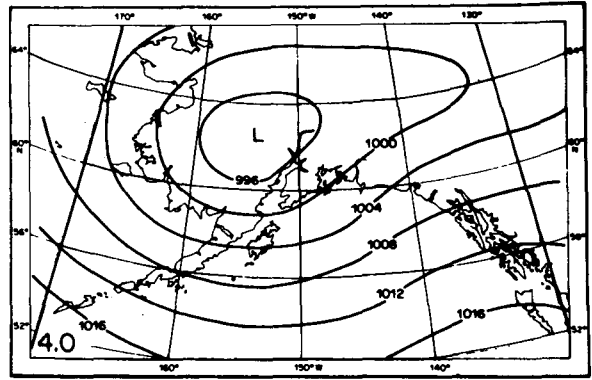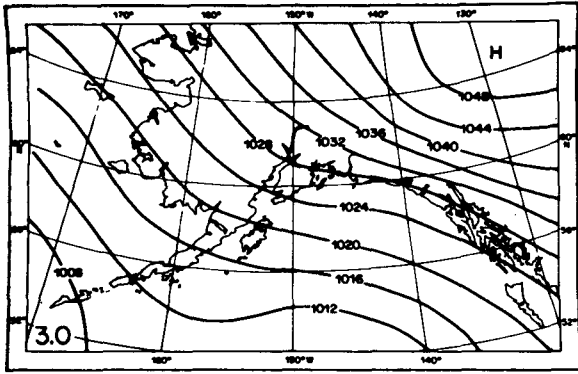
FIG. 3. (Continued)

TABLE 2. Percent of occurrence of each weather type during each season and the transitions from initial type to following type based on 12 h analyses, 1968–77.

Initial type	Occurrence of initial type (%)	Initial type followed by following type (%)					
		1	2	3	4	5	6
Year							
1	12	41	21	5	15	2	16
2	33	11	71	6	7	3	2
3	8	12	17	53	1	1	16
4	18	6	12	0	59	16	7
5	12	0	24	1	15	59	1
6	17	13	2	7	8	3	67
Winter							
1	16	48	20	5	8	1	18
2	32	10	75	8	5	1	1
3	16	9	13	65	0	1	12
4	7	16	18	1	42	11	12
5	3	0	29	4	16	51	0
6	26	11	2	7	3	0	77
Spring							
1	11	35	19	6	19	2	19
2	36	10	71	5	8	3	3
3	7	12	24	44	1	0	19
4	18	4	16	0	56	15	9
5	10	1	34	1	10	53	1
6	18	13	3	6	10	3	65
Summer							
1	6	31	24	3	25	7	10
2	32	7	69	4	8	8	4
3	3	20	22	27	2	9	20
4	25	3	8	0	65	20	4
5	27	0	19	0	12	68	1
6	7	12	7	2	20	8	51
Fall							
1	15	40	21	5	17	1	16
2	32	13	70	6	8	1	2
3	7	15	17	2	2	1	24
4	22	8	13	57	57	14	7
5	7	1	27	29	29	41	2
6	17	15	2	9	8	3	63

1963; Blasing, 1975), which will be compared with the subjective typing in the last section. The procedure is as follows:

1) Correlation coefficients were computed between each 0000 GMT map and all others for the year 1974 using Eq. (1). Accounting for missing data, this formed a correlation matrix of 351 × 351 elements.

2) The daily map which was "highly correlated" with the greatest number of other maps was classified as type A. For this purpose "highly correlated" implies correlation values greater than a cutoff value r_c.

3) All maps which correlated greater than r_c with type A are removed from the analysis.

4) The procedure is repeated to find type B, C, . . . until either all days are classified or they do not correlate with any remaining map. We designate that a type must have a minimum of 10 members.

In following the above procedure, certain arbitrary criteria are adopted in picking r_c. Table 3 shows the number of maps removed (out of 351) at each step of the procedure for three values of r_c. The second column gives the percent of the 351 maps that correlate the greatest with each of the patterns. The second column does not represent the same percentage of 351 maps as the first column. It accounts for some days that were removed from consideration by a pattern which was determined early in the procedure but actually correlated highest with a pattern that was determined late in the procedure.

Table 4 lists the date selected for each objective type A–I (0.8 cutoff) and the correlation with each subjective subtype. Table 5 is a similar format for the 0.7 cutoff types AA–HH. Fig. 5 shows the daily maps for types A through I and Fig. 6 shows the daily maps for types AA through HH. Type A and AA are March and September dates which correlate strongly with subtype 2.0, which is the Aleutian low-pressure center and has the highest percent of occurrence (25%—see the Appendix) in the 1968–77 record of any weather type. Subjective type 6, the second most frequent type, correlates with the second pick of the 0.7 cutoff, type BB. Type B from early September correlates well with 1.3, 3.0, and 6.1, which have east–west oriented isobars associated with lows in the central or southern part of our region. Types F and DD consist of summer cases similar to our subtypes 4.0 and 5.0 which have high pressure to the southeast. Types D and CC are similar to 4.1 and 5.1 with high pressure to the southwest. Type 4 patterns differ from type 5 patterns by having weak lows over interior Alaska. The automated method tended to select for the large-scale pressure gradient directions and placed little weight on small-scale high or low centers even though these centers are of great local meteorological significance. After pattern DD, the number of fits for 0.7 drops by more than half. There were no high-wavenumber transition states picked such as subjective type 2.1.

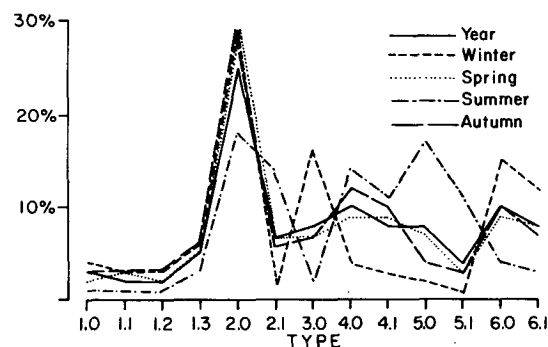The subjective approach and the two automated approaches, typing with 0.7 and 0.8 correlation

FIG. 4. Percentage of occurrence of synoptic weather subtypes by season.

TABLE 3. Number of days which were removed at each stage of the Lund correlation technique. The second column lists the percentage of the data set which correlated the highest with each type. Cutoff values indicate the critical value of the correlation coefficient use in forming the types.

	Cutoff = 0.8			Cutoff = 0.7			Cutoff = 0.6	
Type	Number removed	Maps within the year (%)	Type	Number removed	Maps within the year (%)	Type	Number removed	Maps within the year (%)
A	77	24	AA	102	23	AAA	132	27
B	34	11	BB	49	15	BBB	63	18
C	29	10	CC	42	9	CCC	55	14
D	26	10	DD	44	15	DDD	31	11
E	24	13	EE	19	13	EEE	22	13
F	18	6	FF	17	12	FFF	14	17
G	14	10	GG	13	8	GGG	14	17
H	12	9	HH	10	5			
I	10	7						

threshold, point to four primary patterns: the Aleutian low, type 2; low over the southern Gulf of Alaska, type 6; and east and west high-pressure ridge orientation, subtypes 5.0 and 5.1. After the first four primary patterns, little comparison is possible between the two Lund approaches and the subjective types.

4. Discussion of sequencing weather types

The mechanics of correlation sequencing using digitized pressure maps were described in Section 2. Using this method, the capability of a given set of types to fit a large data set may easily be compared to that of any other set of types.

Fig. 7 plots the percentage of pressure fields from the 1968–77 record, which could be assigned to one of a set of types at a given threshold value of the correlation coefficient. The digitized subjective types are compared with the two sets of types determined by the Lund technique. Also shown is the average of an ensemble of eight cases where 10 pressure fields from 1974 were selected at random and used as types for each run. For the 10-year period

75% of the twice daily weather charts were sequenced with a correlation > 0.7 with one of the subjective subtypes. Fig. 7 shows that both Lund technique type sets perform slightly better than the subjective classification scheme; however, the digitized maps and the correlation types have the same a priori resolution.

The following examples demonstrate certain weaknesses with correlation sequencing. Fig. 8 shows a pressure field that correlated well ($r = 0.93$) with subtype 1.0. By comparing Fig. 8 with subtype 1.0 (Fig. 3) we see that the assignment was based on the relative depth of the central depression. The edge features and relatively small areas of flat pressure gradient were apparently ignored. Fig. 9 shows a pressure field assigned to subtype 1.0 with a poor correlation ($r = 0.66$). On meteorological grounds we would call both Figs. 8 and 9 good examples of a subtype 1.0 storm but with differing intensity near the center. The poor correlation in this case is due to the difference in the second derivative of the pressure fields, the shape of a radial cross section of the depression, and to the openness of the low at the eastern edge. Fig. 10 shows a 0.85 correlation

TABLE 4. The correlation between the correlation types for 0.8 cutoff and the 13 subjective types. Numbers in italics indicate maxima for each correlation type.

		Subjective types													
Type	Date	1.0	1.1	1.2	1.3	2.0	2.1	3.0	4.0	4.1	5.0	5.1	6.0	6.1	Closest fit
A	3-23-74	0.03	0.35	−0.05	0.70	*0.96*	0.50	0.63	0.09	−0.78	0.07	−0.72	−0.35	−0.00	2
B	9-08-74	0.39	0.73	0.26	*0.90*	0.69	−0.12	*0.90*	−0.51	−0.71	−0.78	−0.95	0.51	0.80	1 or 3
C	1-16-74	0.65	0.67	0.53	0.40	−0.12	−0.53	0.33	−0.50	0.09	−0.89	−0.33	0.82	*0.92*	6
D	7-10-74	0.06	−0.24	−0.00	−0.64	−0.87	−0.11	−0.85	0.41	*0.86*	0.26	0.83	−0.05	−0.19	4
E	8-08-74	−0.24	−0.25	−0.30	−0.09	0.33	*0.76*	−0.32	0.76	−0.07	*0.84*	0.19	−0.94	−0.73	5
F	7-04-74	−0.39	−0.61	0.38	−0.74	−0.51	0.36	−0.87	0.76	0.52	*0.88*	0.84	−0.70	−0.84	5
G	4-14-74	0.43	0.70	0.07	*0.78*	0.69	0.38	0.43	0.29	−0.52	−0.23	−0.65	−0.12	0.39	1
H	1-13-74	0.32	0.44	0.47	0.44	0.19	−0.67	0.74	−0.89	−0.29	−0.83	−0.55	*0.87*	0.74	6
I	10-03-74	0.51	0.14	0.68	−0.28	−0.56	−0.60	−0.21	−0.28	*0.73*	−0.28	0.40	0.51	0.30	4
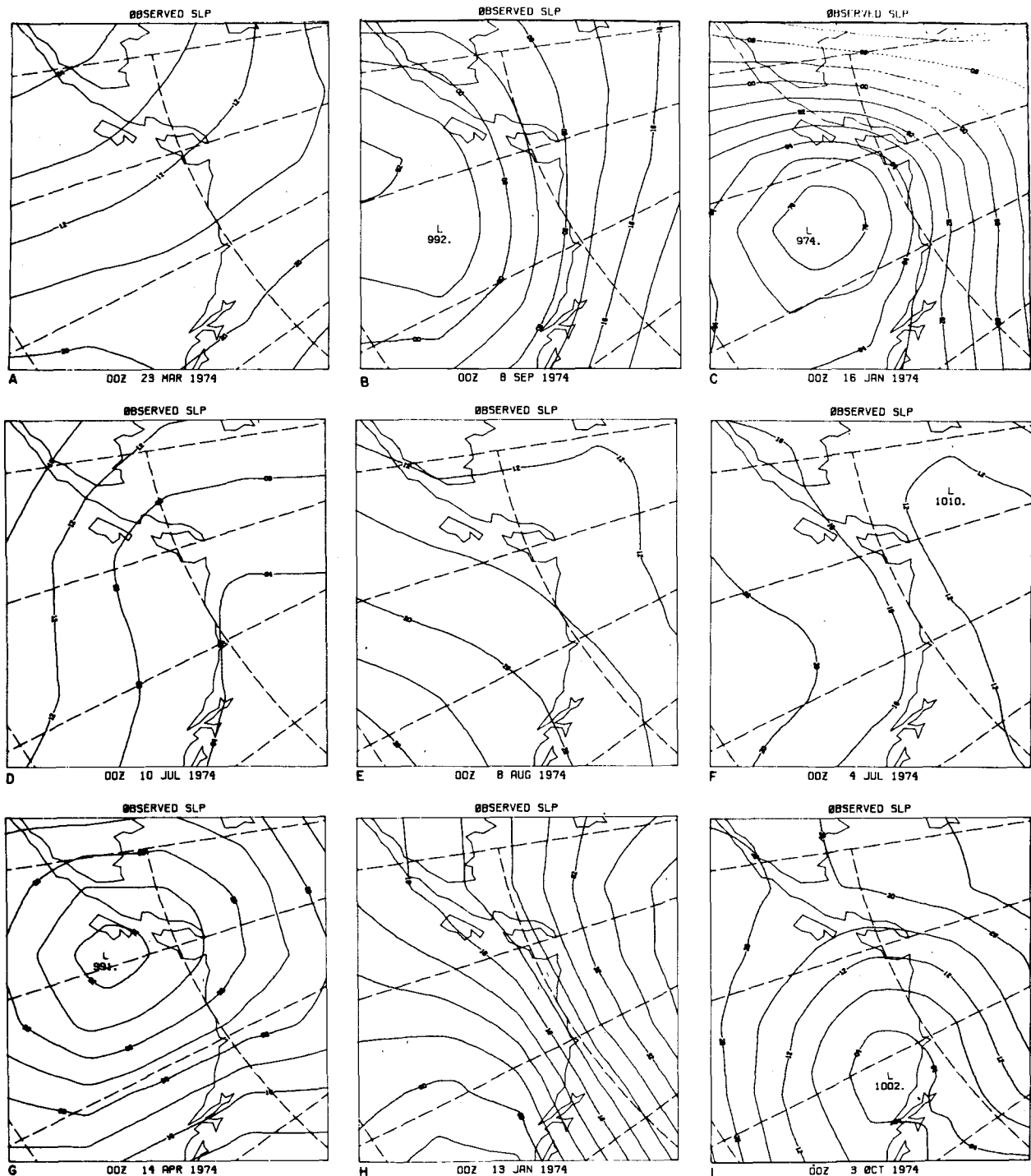
FIG. 5. Lund map types A–I for r = 0.8 cutoff value.

with type 3.0. On meteorological grounds this is a subtype 6.1, as there is clearly a low-pressure center in the central GOA and the high in the interior is not predominant. This example represents a mis-assignment of type at a fairly high value of r.

A pressure field may also be assigned to a type by the subjective interpretation of the hand-analyzed analyses by a synoptic meteorologist. Assignments were made by correlation and subjective sequencing methods for February and March 1975.

Table 6 shows the number of occurrences where the subjective assignment differed from the correla-tion.assignment. For example, the correlation method made two assignments to type 6.0 which the meteor-
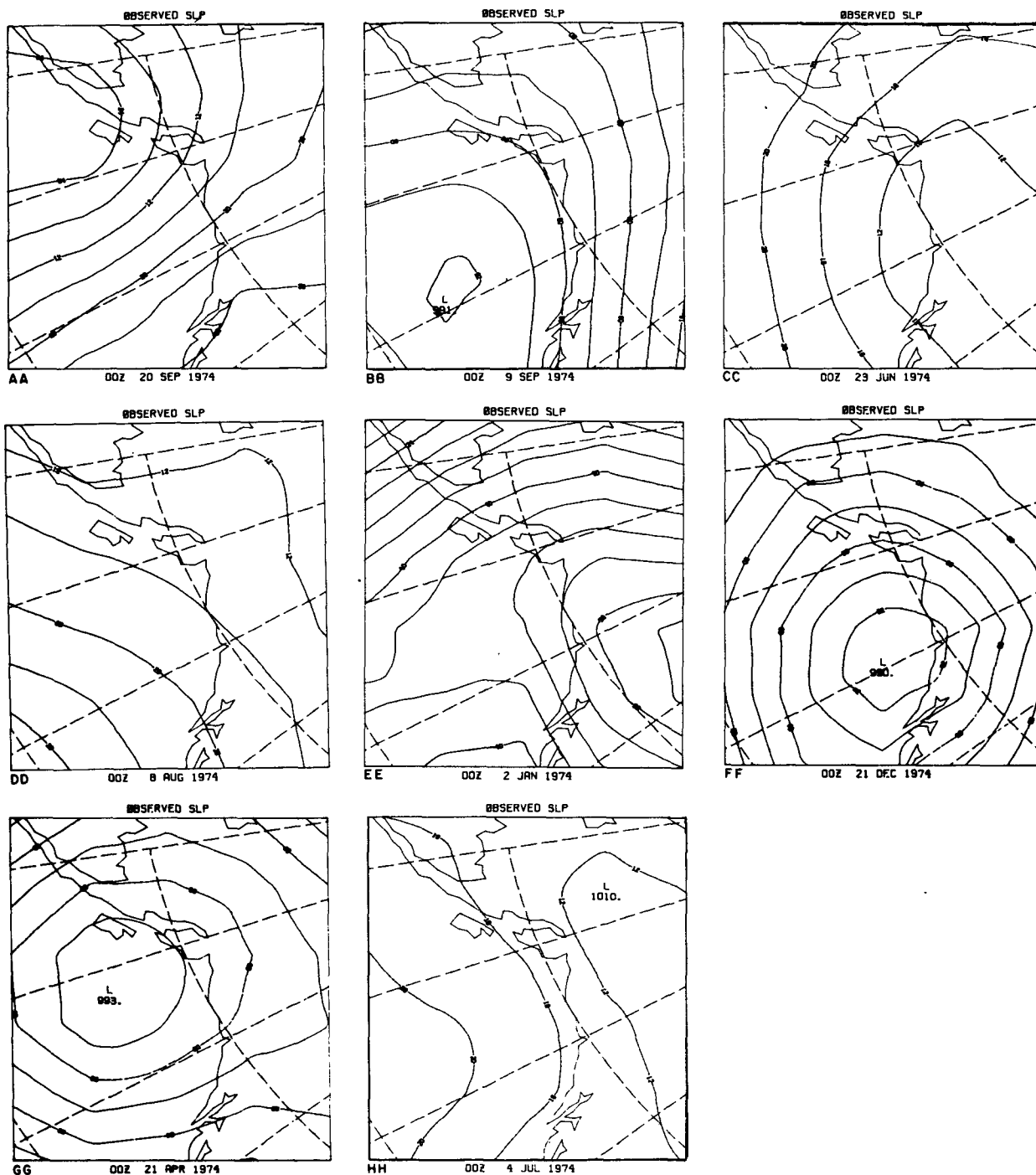
FIG. 6. Lund map types AA–HH for $r = 0.7$ cutoff value.

ologist assigned to type 1.2. The asterisks occur where the correlation between subtypes > 0.60, which indicates the likelihood of ambiguity between these subtypes.

Out of 115 correlation method assignments, 45 (39%) were reassigned by subjective assignment. However, only 28 (24%) of the correlation method assignments were reassigned to a type that correlated less than $r = 0.6$ with the original choice. Subtypes 2.0 and 2.1 are meteorologically related but poorly correlated. Subtypes 6.0 and 3.0 are well correlated when the low of subtype 6.0 is far to the southeast. Neglecting misassignments between these subtypes, only 15 (13%) of the maps were completely misassigned.

Summing the counts in the columns of Table 6 gives the gain by reassignment for each subtype. Summing the rows gives the loss to each type. The

TABLE 5. As in Table 4 except for 0.7 cutoff.

Type	Date	Subjective types													Closest fit
		1.0	1.1	1.2	1.3	2.0	2.1	3.0	4.0	4.1	5.0	5.1	6.0	6.1	
AA	9-20-74	0.13	0.53	-0.07	0.86	*0.94*	0.48	0.69	-0.00	-0.83	-0.19	-0.86	-0.17	0.27	2
BB	9-09-74	0.55	0.69	0.51	0.57	0.18	-0.65	0.70	-0.63	-0.29	-0.94	-0.60	0.88	*0.93*	6
CC	6-23-74	0.19	-0.22	0.17	-0.65	-0.77	-0.06	-0.85	0.49	*0.92*	0.36	0.85	-0.19	-0.28	4
DD	8-08-74	-0.24	-0.25	-0.30	-0.09	0.33	0.76	-0.32	0.76	0.07	*0.84*	0.19	-0.94	-0.73	5
EE	1-02-74	-0.08	0.18	0.06	0.51	0.80	0.04	0.78	-0.34	-0.78	-0.07	-0.66	0.01	0.02	2
FF	12-21-74	0.70	0.41	0.69	-0.05	-0.47	-0.62	-0.11	-0.18	0.60	-0.52	0.20	0.65	0.58	1
GG	4-21-74	0.57	0.72	0.18	0.59	0.25	0.19	0.14	0.29	-0.11	-0.38	-0.38	0.08	0.57	1
HH	7-04-74	-0.39	-0.61	-0.38	-0.74	-0.51	0.36	-0.87	0.76	0.52	*0.88*	0.84	-0.70	-0.84	5

difference of the two gives the net gain or loss due to the subjective modification of the correlation sequencing. These numbers appear in the bottom row of Table 6. The major losses are types 2.0, 3.0 and 6.0, whereas the gains are in subtypes 2.1 and 6.1. Much of type 2.0 was reassigned to type 2.1. Type 2.1 is a very detailed type in that it has higher wavenumber features than most other types. Type 3.0 losses are due to mismatch of the second derivative of the pressure field in the coastal region where packing of the isobars is the noted feature, again a high wavenumber problem. The confusion between subtypes 6.0 and 6.1 is a manifestation of the low centers being edge features.

Edge features and very detailed subjective types are not clearly seen in the correlation sequencing technique, at least not on the grid mesh being used.

Therefore, if a 10-year record were subjectively sequenced and compared to Table 2, one would expect less of the simple types and more of the high-wavenumber types. This inability of the correlation method to see detailed features helps explain why the Lund typing technique produced redundant types rather than detailed transitional types. Any objective pattern technique will be limited by lack of resolution on digitized fields when compared to subjective typing from hand-plotted charts.

5. Conclusion

We have specialized two existing subjective climatologies for the coastal region of the Gulf of
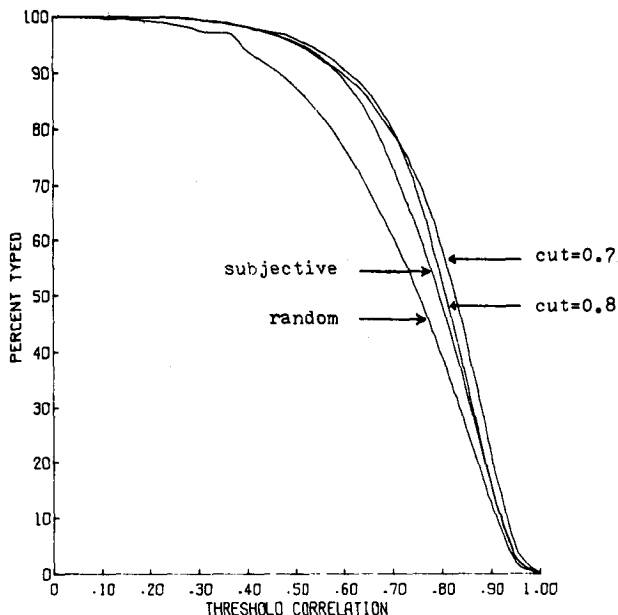

FIG. 7. Percentage of 12 h NMC digitized sea level pressure charts (1968–77) sequenced by the subjective patterns, the two sets of pattern correlation types, and the average of eight sets of ten maps drawn at random from the NMC data set from 1974 as a function of minimum correlation value.
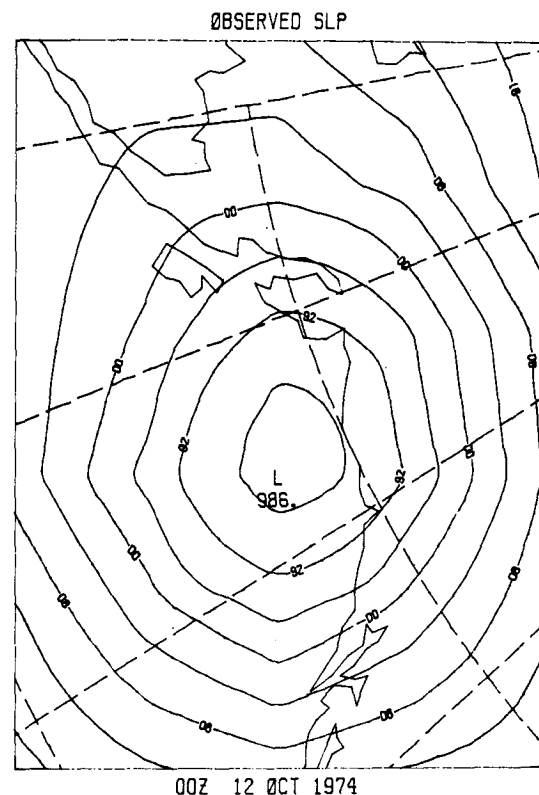
FIG. 8. A daily map that correlated well with type 1.0 ($r = 0.93$).
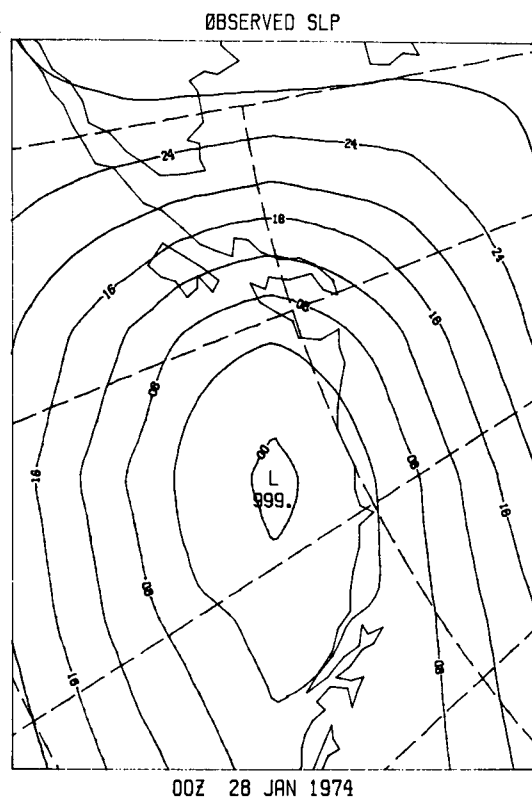
OBSERVED SLP

OBSERVED SLP

FIG. 9. A pressure field that was assigned to type 1.0 with a low correlation ($r = 0.66$).
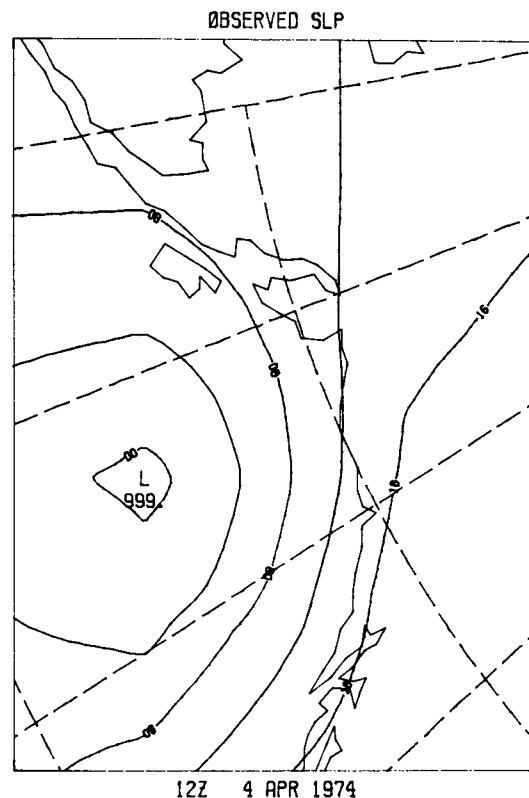
FIG. 10. A pressure field that correlated well with type 3.0 ($r = 0.85$) despite its resemblance to type 6.1.

Alaska and contrasted it to the Lund approach. We have also investigated various approaches to sequencing daily weather charts.

The four basic persistent patterns were identified by all approaches. Beyond these four, migratory lows were grouped into various types. Correlation-based techniques for typing and sequencing, which normalize the pressure patterns, had great difficulties with high-wavenumber features or with features at the edge of the region. Other techniques based on covariance, which also considers pattern intensity, may be more successful. Matching maps based on comparing the first n coefficients of empirical orthogonal functions of a yearly data set could be more selective than correlation sequencing. However, all objective techniques are *a priori*

TABLE 6. The number of charts out of 115 for February–March 1975 in which subjective sequencing specified a different pattern choice than the objective correlation approach. The last row lists the net change to each subtype due to subjectively reassigning subtypes. The asterisks indicate where two subtypes correlated greater than 0.6.

Correlation method	Subjective method												
	1.0	1.1	1.2	1.3	2.0	2.1	3.0	4.0	4.1	5.0	5.1	6.0	6.1
1.0	*	*	*	0	0	0 .	0	0	0	0	0	0	*
1.1	*	*	0	*	0	0	0	0	0	0	0	0	*
1.2	*	0	*	0	0	0	0	0	0	1	1	1	0
1.3	1	*	0	*	*	0	*	0	0	0	0	0	1*
2.0	0	0	0	3*	*	8	1*	3	0	1	0	0	0
2.1	0	0	0	0	0	*	0	1	0	0	0	0	0
3.0	0	0	0	*	*	0	*	0	0	0	0	5	2*
4.0	0	0	0	0	0	2	0	*	1	*	0	0	0
4.1	0	0	0	0	0	0	0	0	*	0	*	0	0
5.0	0	0	0	0	0	0	0	1*	0	*	*	0	0
5.1	0	0	0	0	0	0	0	0	*	*	*	0	0
6.0	0	0	2	0	0	0	0	0	0	0	0	*	8*
6.1	1*	*	1	*	0	0	*	0	0	0	0	*	*
Net gain	2	0	0	1	−16	9	−6	2	1	1	1	−4	9

suspect for certain applications because the information in objectively based synoptic-scale grid point fields is limited.

The information in our patterns specifies the direction and the relative magnitude of the geostrophic wind over the region. In application we scaled our pattern information with the magnitude of the wind speed provided at several offshore buoy locations.

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APPENDIX

Percent Occurrence of each Subtype by Year and Season

1. Year

Initial type	Following type												
	1.0	1.1	1.2	1.3	2.0	2.1	3.0	4.0	4.1	5.0	5.1	6.0	6.1
1.0	26	2	9	1	10	5	1	13	18	1	0	3	11
1.1	15	17	4	7	9	2	2	17	9	1	1	6	10
1.2	3	2	18	3	31	4	11	4	2	8	1	6	7
1.3	3	13	1	30	18	3	6	5	1	0	0	3	17
2.0	1	1	0	8	69	5	7	5	0	3	0	0	1
2.1	1	1	1	6	27	35	2	16	1	4	1	1	4
3.0	1	2	1	8	17	0	52	1	0	1	0	8	9
4.0	2	1	0	1	6	11	0	49	10	10	7	1	2
4.1	2	0	5	0	4	3	0	6	55	5	9	7	4
5.0	0	0	0	0	17	17	1	9	0	52	4	0	0
5.1	0	0	0	0	3	3	0	7	17	20	49	1	0
6.0	2	1	6	0	3	0	8	1	9	1	3	56	10
6.1	7	6	2	3	1	1	5	1	5	0	0	26	43
Percent occurrence	3	2	2	5	25	7	8	10	8	8	4	10	8

2. Fall

Initial type	Following type												
	1.0	1.1	1.2	1.3	2.0	2.1	3.0	4.0	4.1	5.0	5.1	6.0	6.1
1.0	27	4	5	0	11	5	2	21	14	0	0	0	11
1.1	18	15	4	2	9	2	4	21	5	0	0	9	11
1.2	8	2	16	2	40	2	10	0	2	6	2	2	8
1.3	5	15	0	27	17	3	5	6	2	0	0	2	18
2.0	0	2	0	11	66	5	7	6	0	2	0	0	1
2.1	1	2	1	6	40	25	2	19	0	0	0	1	3
3.0	2	1	1	11	17	0	40	2	1	1	0	11	13
4.0	3	3	0	1	5	10	1	47	14	8	5	2	1
4.1	1	0	8	1	5	4	0	2	53	6	8	7	5
5.0	1	0	0	0	25	14	0	23	0	34	3	0	0
5.1	0	0	0	0	9	3	0	12	24	12	37	3	0
6.0	1	1	8	0	2	0	11	1	7	1	4	59	5
6.1	8	7	5	2	0	1	6	2	6	0	0	26	37
Percent occurrence	3	3	3	6	26	6	7	12	10	4	3	10	7

3. Winter

Initial type	Following type												
	1.0	1.1	1.2	1.3	2.0	2.1	3.0	4.0	4.1	5.0	5.1	6.0	6.1
1.0	31	1	13	0	11	4	1	6	10	0	0	7	16
1.1	18	22	6	16	10	4	0	4	4	0	0	4	12
1.2	0	0	21	6	36	0	12	4	0	4	2	11	4
1.3	3	13	1	30	18	3	6	6	1	0	0	3	16
2.0	1	1	0	7	73	2	9	4	0	1	0	1	1
2.1	3	0	6	8	46	17	0	11	0	3	0	0	6
3.0	1	2	1	6	13	0	65	0	0	1	0	6	5
4.0	9	0	2	0	12	14	2	31	9	9	6	3	3
4.1	11	0	10	0	5	5	0	4	39	2	4	13	7
5.0	0	0	0	0	36	3	6	12	0	40	3	0	0
5.1	0	0	0	0	6	0	0	0	25	25	44	0	0
6.0	1	1	3	0	2	0	9	0	3	0	0	67	14
6.1	8	7	2	2	1	0	5	0	2	0	0	20	53
Percent occurrence	4	3	3	6	29	2	16	4	3	2	1	15	12

4. Spring

Initial type	Following type												
	1.0	1.1	1.2	1.3	2.0	2.1	3.0	4.0	4.1	5.0	5.1	6.0	6.1
1.0	17	3	3	6	9	6	0	14	33	0	0	3	6
1.1	9	14	2	7	9	2	5	20	14	2	0	7	9
1.2	0	7	20	3	19	3	10	10	3	6	0	6	13
1.3	1	12	0	29	20	3	8	3	1	0	0	3	20
2.0	1	2	0	7	70	4	6	5	0	2	0	1	2
2.1	0	2	0	9	32	24	1	20	1	3	1	2	5
3.0	0	3	1	8	23	2	43	1	0	0	0	8	11
4.0	1	1	1	1	7	16	0	46	7	9	6	2	3
4.1	1	1	4	0	6	2	0	4	55	9	6	7	5
5.0	0	0	1	0	22	20	2	4	1	45	4	1	0
5.1	0	0	0	0	6	4	0	2	21	35	32	0	0
6.0	2	1	7	0	3	0	9	1	12	2	4	49	10
6.1	7	4	1	4	1	0	4	1	6	0	0	29	43
Percent occurrence	2	3	2	5	29	7	7	9	9	7	3	9	8

5. Summer

Initial type	Following type												
	1.0	1.1	1.2	1.3	2.0	2.1	3.0	4.0	4.1	5.0	5.1	6.0	6.1
1.0	15	0	10	0	10	10	0	15	30	5	0	0	5
1.1	7	14	0	0	0	0	35	29	0	7	0	7	1
1.2	5	0	11	0	16	21	11	5	5	26	0	0	0
1.3	2	8	0	29	19	8	3	11	2	0	2	3	13
2.0	0	0	0	7	63	11	6	2	0	8	0	1	2
2.1	0	1	0	5	16	46	2	14	2	7	2	2	3
3.0	2	2	7	9	22	0	27	0	2	9	0	9	11
4.0	1	0	0	0	3	9	0	55	7	13	10	0	2
4.1	2	1	2	0	1	2	0	11	58	3	14	5	1
5.0	0	0	0	0	12	17	0	7	0	59	5	0	0
5.1	0	0	0	0	0	2	0	8	14	17	58	1	0
6.0	4	0	6	0	4	0	1	1	23	3	9	39	10
6.1	5	2	2	5	4	7	4	3	11	0	3	33	21
Percent occurrence	1	1	1	3	18	14	2	14	11	17	11	4	3

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